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LAND RESOURCES INVENTORY OF LIGNITE STRIP-MINING AREAS, EAST TEXAS

AN APPLICATION OF ENVIRONMENTAL GEOLOGY

CHRISTOPHER D. HENRY



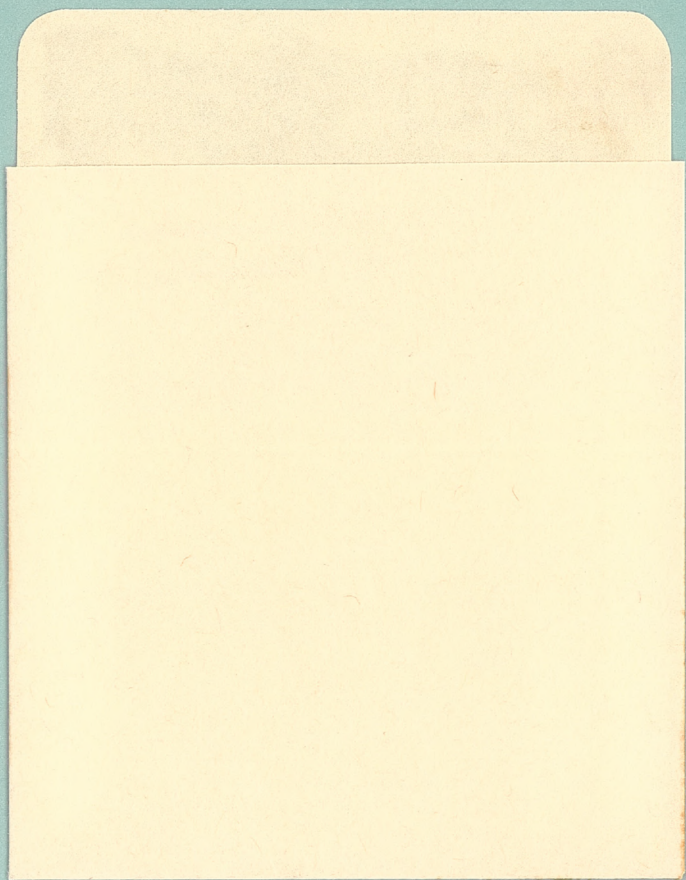
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LAND RESOURCES INVENTORY OF LIGNITE STRIP-MINING AREAS, EAST TEXAS

Christopher D. Henry

INTRODUCTION

With the growing concern for finding new sources of energy, there has been renewed interest in an old source, lignite. In the past few years, Texas lignite has been "rediscovered", and a wave of lignite exploration rivals the early oil booms of Texas history. Present heavy leasing activity will be followed during the next decade by the development of numerous mines.

Surface mining of coal in other parts of the country has created many environmental problems. Particularly in Appalachia and the Midwest, these problems have given the American public a poor image of coal mining. Too often in the past, attempts to solve the problems have consisted of inventories of environmental degradation after mining begins and after meaningful preventive treatment could have been implemented. Though these studies are necessary, they can only help solve the problems if the knowledge gained is applied in advance to areas where mining is about to be initiated. An understanding of the problems will permit mine operators to implement preventive measures before mining commences.

Concern over potential environmental degradation from present and future lignite mining in Texas has led the Texas Legislature to pass the "Texas Surface Mining and Reclamation Act" (Texas Legislature, 1975). To be effective, the act must be applied knowledgeably, based on a thorough understanding of the mechanisms of mining, the potential environmental effects of mining, the ways in which these effects will interact with the land and water, and the basic character of the land that will be affected by the mining.

This report is concerned primarily with the last two points, though the others are also considered. It explains the application of environmental geologic mapping to lignite mining and indicates how the mapping can be used to avoid or alleviate potential environmental problems; it also illustrates the various considerations that go into environmental geologic mapping and environmental planning in general. Significant lignite

deposits occur in sections of eastern and southern Texas (fig. 1). This circular describes work done in a part of East Texas which has two mines operating currently with more planned to open in the near future. An environmental geologic map of this region is in preparation.

HISTORY OF LIGNITE MINING IN TEXAS

Until recently lignite was not considered a significant resource, yet the history of lignite mining extends back to the early 1800's. By 1890, Texas lignite production was about 15,000 tons per year and growing rapidly; it reached a million tons per year several times between 1910 and 1930. (For more detailed figures, see Kaiser, 1974.) As the availability of inexpensive oil and gas increased, lignite production declined; in the early 1950's, production had dropped to about 18,000 tons per year.

Early mining was almost entirely underground by room-and-pillar methods. The last underground mine, at Darco (fig. 1), was converted in 1944 to a surface mine. Where lignite occurred at shallow depths close to the outcrop, a primitive form of strip mining was used. Holes up to 30 feet in diameter were dug, the overburden piled nearby, and the lignite extracted. Pits of this type are still visible in many parts of East Texas, particularly about 5 miles northeast of Alcoa (fig. 1) both north and south of U. S. 79.

Lignite is presently mined by a technique called area stripping (fig. 2). In flat to gently rolling terrain where the lignite covers a large continuous area, overburden is removed in a series of rows. Overburden from the first row is piled next to the pit away from the direction mining will take, and the lignite is removed. Subsequent cuts are made parallel to the first and the overburden is deposited in the immediately preceding pit.

Preliminary figures from the four active mines in Texas (fig. 1) indicate that about 11.4 million tons of lignite was produced—an increase of almost

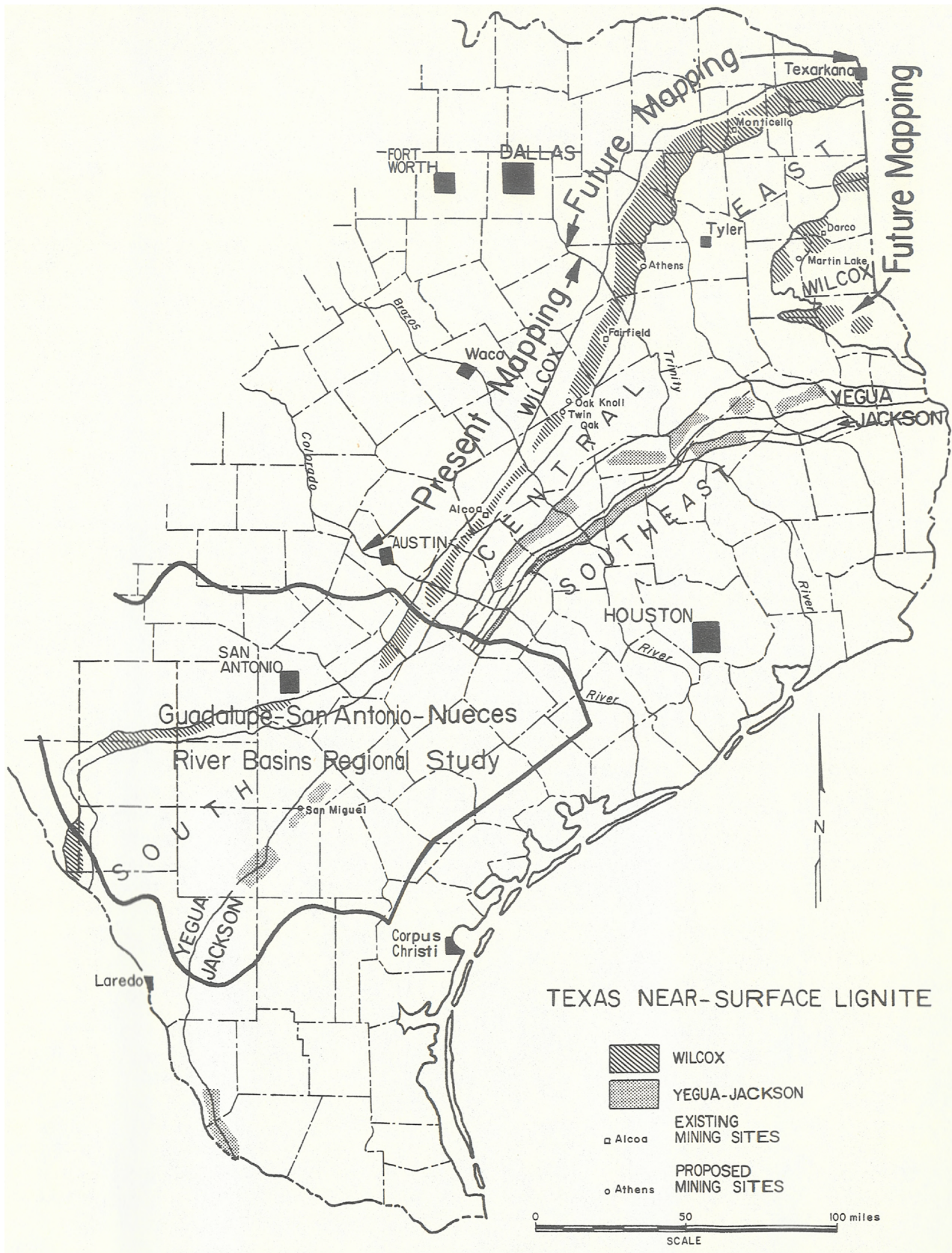


Figure 1. Map of East and South Texas showing distribution of near-surface lignite, active and planned lignite mines, and present and future environmental geologic mapping.

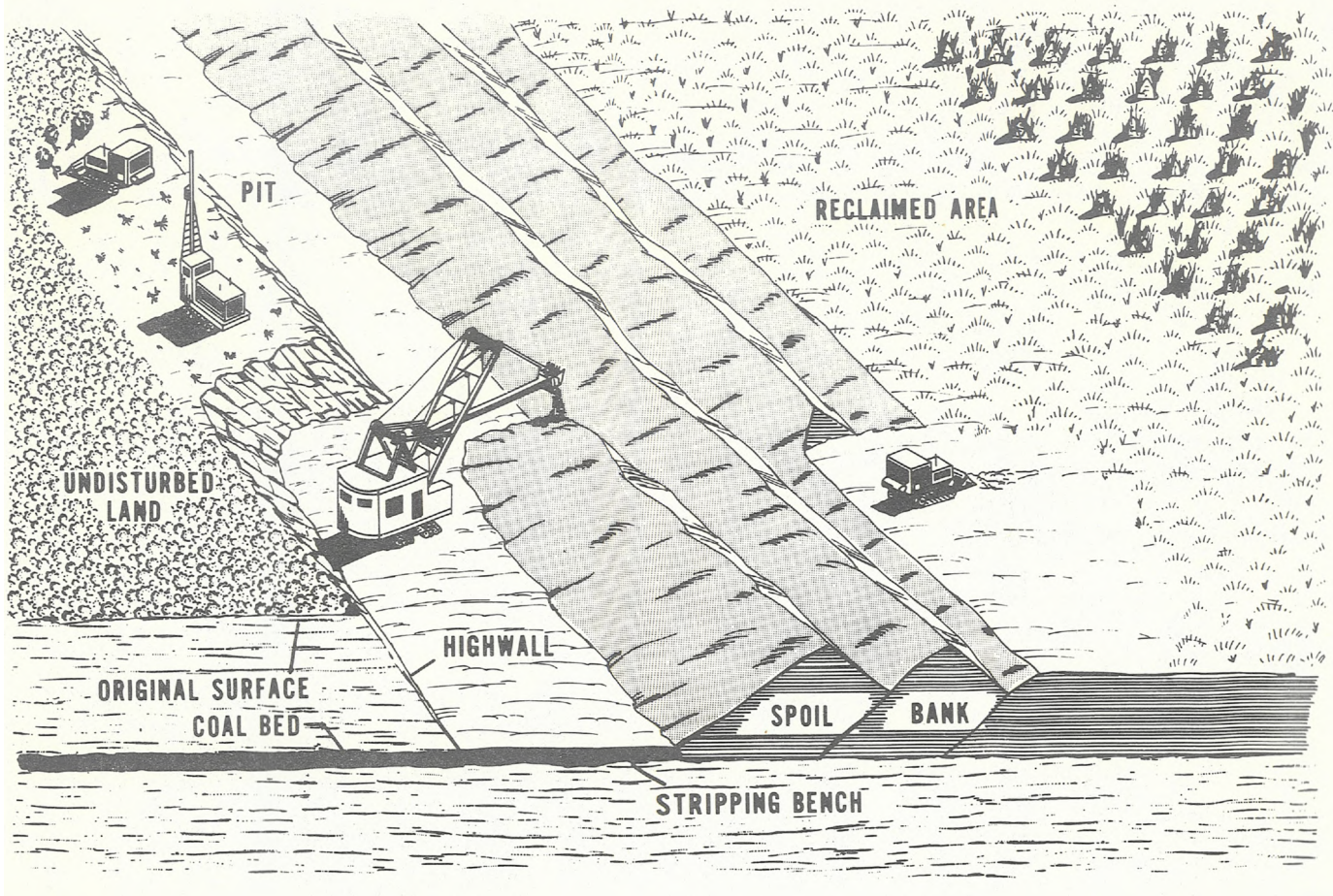


Figure 2. Area strip mining with concurrent reclamation; from Grim and Hill (1974).

50 percent over 1974. The first strip mine in Texas started in 1944 at Darco; the lignite was and still is used to produce activated carbon. A mine at Alcoa opened in 1954 to supply a power plant for aluminum reduction, even though oil and gas were abundant and inexpensive at that time. Two mines, run by Texas Utilities Generating Company at Fairfield and Monticello, opened in 1971 and 1974, respectively; the company has practiced reclamation since the inception of these mines. The older two mines have recently started reclamation programs; both also plan to restore older mined lands.

Numerous other lignite mines and power plants are in various stages of development. Production for 1985, based on 1975 data of the Electric Reliability Council of Texas, is projected to be about 75 million tons (Electric Reliability Council of Texas, 1975). At that rate, mining would annually disturb approximately 6,000 acres, assuming that the average mined lignite seam is 7

feet thick. Thus by 1985, Texas will be among the major coal-producing states in the United States.

ENVIRONMENTAL PROBLEMS ASSOCIATED WITH COAL MINING

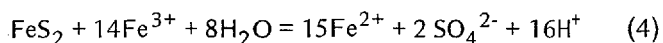
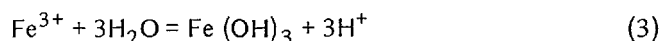
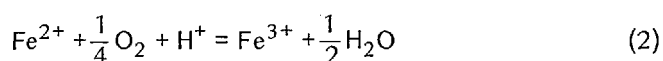
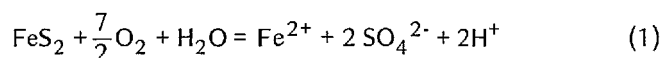
Surface mining for coal in other parts of the nation has caused severe environmental problems when conducted improperly or when the planning envisioned in this report was not done prior to mining. A review of a few of the environmental problems will identify some of the critical considerations in mine planning. It should be understood, however, that the existence of these problems elsewhere does not indicate their existence in Texas; it means only that they need to be considered, understood, and planned for.

Environmental concerns related to surface mining can be grouped into three general types: erosion-sedimentation, water pollution, and rec-

lamation. Surface mining removes the original vegetation cover plus a variable amount of overburden from above the lignite. The overburden is left in large piles which erode easily if not regraded and revegetated. If the sediments derived from erosion are not trapped, they may enter the surface drainage system and increase the suspended load, thus lowering the general quality of the water and reducing potential use.

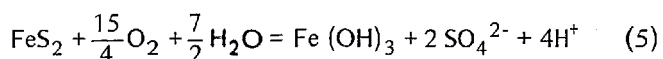
Coal and its associated overburden commonly contain pyrite and other sulfides. When exposed to weathering, pyrite oxidizes to form sulfuric acid and releases iron and other elements that are soluble in aqueous solutions. The result is acid mine drainage which has been a problem in Appalachia and the Midwest.

The precise chemical reactions involved in pyrite oxidation are debated, but a frequently cited model is that of Stumm and Morgan (1970):



Initial oxidation of pyrite proceeds by reaction 1. From there ferrous iron is oxidized to ferric iron (reaction 2) and ferric iron precipitates as ferric hydroxide (reaction 3). Once these reactions are initiated, pyrite can also be oxidized by ferric iron (reaction 4).

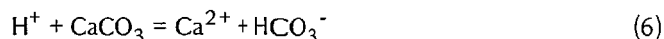
Reactions 1 through 3 can be summarized by:



For each mole of pyrite oxidized, four moles of acidity and two moles of sulfate are produced.

Texas is fortunate in that much of the lignite here is low in sulfur (Kaiser, 1974), thus low in pyrite. Some Texas lignites, particularly in South Texas, contain considerably greater amounts of sulfur (Kaiser, 1974) than the generally low-sulfur lignite of East Texas. Texas lignite and overburden commonly contain calcite and other carbonate

minerals which can neutralize acid produced by weathering of pyrite. The neutralization reaction is:



Acid-drainage problems have not been found in any lignite mine in Texas (Lentz, 1975; W. A. Steingraber, personal communication, 1975). Trace elements such as copper, lead, and zinc which are readily soluble in acid waters are less soluble in natural waters and are commonly adsorbed by ferric hydroxide during precipitation (reaction 3) (Hem and Skougstad, 1960). However, even neutralized mine drainage is commonly of poorer quality than the natural surface or ground water (Hollyday and McKenzie, 1973). Lentz (1975) studied the hydrology and mine-water chemistry of the Texas Utilities mine near Fairfield. None of the waters analyzed were acid, but some contained moderately high sulfate contents up to 1,800 milligrams per liter (mg/l) indicating that pyrite had been oxidized but that the acid produced had been neutralized. One location had a high iron content, 65 mg/l. Fortunately most samples from ponds in the mine area showed neither acid waters nor high sulfate values.

Both erosion and acid production are aggravated if the mined land is not reclaimed—graded into a more or less natural contour and revegetated. Unreclaimed land generally has no practical use; it is a wasted resource. Land can be regraded, the soil replaced if necessary, and vegetation reestablished. If done properly the land can be as productive as it was before mining.

If original soils are not preserved, the newly graded surface layer will be composed of mixed lignite and overburden. This material will not have been previously exposed to weathering and will develop a pH based on the interaction of the oxidation of pyrite and the buffering of carbonate minerals. The surface material may have unusual abundances of trace elements derived from the coal or associated overburden. In surface material with high acidity, the availability of many elements (for instance iron, copper, aluminum, and manganese, see Johnson, 1965) may increase to the point that the surface material is toxic to plants. Even if the acid is neutralized and vegetation is established, trace elements in anomalous concentrations may

be taken up by the plants grown on the reclaimed area, thus entering the food chain. In this situation, productive reclamation may not be possible.

CLIMATE

The two areas in Texas with major lignite deposits, East and South Texas, have distinctly different climates which will influence differently the way in which lignite mining will affect the environment. Figure 3 illustrates several significant

features of the Texas climate; the most notable feature is variability.

Climate contributes significantly to three factors considered in the present study: flooding, revegetation of reclaimed land, and acid production by oxidation of pyrite. East Texas is an area of heavy precipitation, and all areas of Texas containing lignite deposits are subject to short, intense storms. Tropical storms from the Gulf of Mexico and convective thunderstorms have produced both national and world record rainfalls and

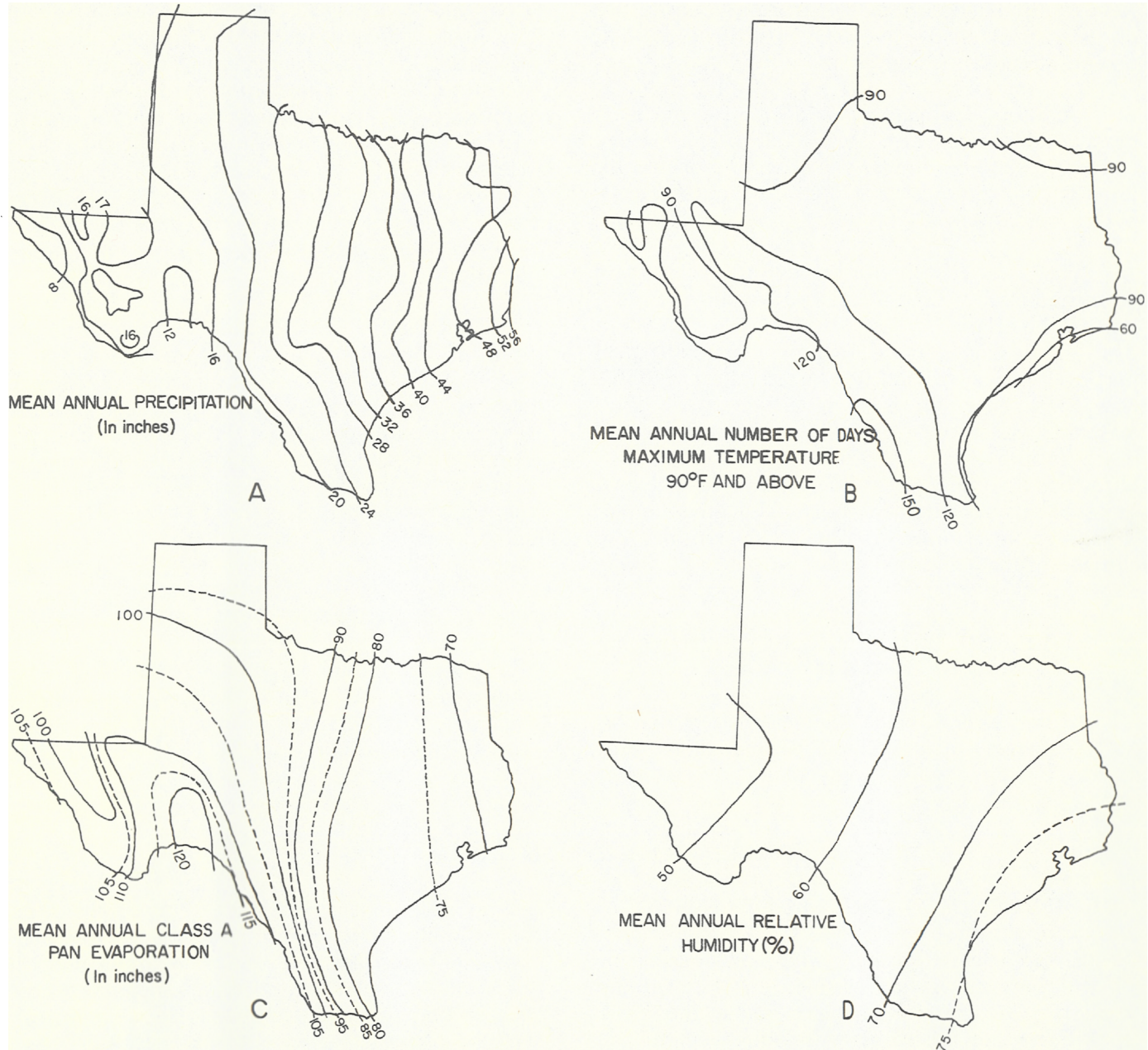


Figure 3. Texas climatic factors; from the Climatic Atlas of the United States (U. S. Department of Commerce, 1968).

floods commensurate with those rains (Baker, 1975; Patterson, 1963).

Climate is a major consideration in reclamation planning. Temperature and rainfall together determine type and thickness of soil, type and abundance of vegetation, and potential for agriculture. Warm areas with moderate to heavy rainfall will revegetate relatively easily following mining, assuming that the reclaimed surface material does not contain excessive toxic materials or that original soils are saved and returned. Revegetation is essential for future productive use of reclaimed land. In areas with low rainfall, revegetation is more difficult.

Acid production by oxidation of pyrite is most rapid in a warm, humid climate; in a dry climate, pyrite oxidation will proceed more slowly (Smith and Shumate, 1971). In South Texas, pyrite oxidation may be slower than in East Texas.

Historical evidence indicates that reclamation of mined land in East Texas, with its high rainfall, should be relatively easier than in drier areas. In East Texas unreclaimed land near Darco (fig. 1) that was mined in the late 1940's and early 1950's now has thick stands of pine where the spoil material was not so steep that erosion prevented revegetation. Coal mining around 1920 near Laredo where rainfall is roughly half that of East Texas left spoil piles which are still unvegetated. Reclamation planning will need to consider the climate of the individual area.

REVIEW OF TEXAS SURFACE MINING AND RECLAMATION LAW

"The Texas Surface Mining and Reclamation Act" charges the Railroad Commission with

regulating surface mining, administering the bill, and monitoring reclamation programs. As several requirements set forth in the bill are met by the environmental geologic mapping discussed in this report, it is useful to present a generalized review of some of the requirements.

Sections of the bill require that mining companies identify the natural capability of the land prior to mining, control erosion and sedimentation into surface water, avoid chemical pollution of ground and surface water, provide adequate topsoil of sufficient quality for revegetation, and minimize the disturbance to the prevailing hydrologic balance. In addition, the bill states that certain areas may be deemed unsuitable for surface mining, including (1) areas in which reclamation is unfeasible, (2) areas of frequent flooding or unstable geology, (3) aquifers and aquifer recharge areas, or (4) areas of important natural systems that would be damaged significantly by mining operations.

Considerable information concerning the land, its capability, and its sensitive areas is necessary to avoid major environmental damage from the mining process. With the proper information, such damage can be avoided. The environmental geologic mapping described in this report is intended to provide the necessary basic information for environmental planning related to mine design, operation, and reclamation.

ACKNOWLEDGMENTS

Research on lignite strip-mining was sponsored in part by the U. S. Geological Survey, Department of the Interior, under U.S.G.S. Grant No. 14-08-0001-G-316.

ENVIRONMENTAL GEOLOGIC MAPPING

DEFINITION AND CRITERIA OF MAPPING

Environmental geologic mapping undertaken in the present study delineates the various properties of the land which define the basic capabilities and the types of productive use that the land can sustain. Environmental mapping of lignite-bearing areas includes several factors besides

geology. All units are defined with emphasis on their usefulness in planning mining and reclamation. The criteria for defining and mapping units in this study are substrate, soil, biologic assemblage, geomorphology (land form and slope intensity), geologic process, and man's influence. For many map units the criteria are interrelated. A specific substrate develops a certain land form and type of

soil which in turn supports a particular vegetation cover. Together these factors determine man's use of the land.

One map unit, strip-mined land, is based entirely on man's activities. This unit is ultimately governed by geology, however, because the mining would not have occurred without the presence of some mineral resource, for example, lignite or sand and gravel.

Combining several diverse criteria to designate environmental geologic units is unusual. Most previous studies have separated physical properties, processes, and topography and terrain to produce a suite of maps, one for each variable (Alabama Geological Survey, 1971). This study produced one map, combining several variables in one map unit because the variables generally correlate well. For instance, areas with sand substrates commonly have very sandy soils, form hills with moderate to steep slopes, support post oak forests, and are recharge areas. Separating the variables would produce a suite of nearly identical maps. The most notable exception is the floodplain unit where process, flooding, is of overriding concern and is the only factor used in defining the unit. Even there the substrate and soil, though variable, are characterized by a commonly recurring vertical sequence. Relief on floodplains is minor. All three factors are determined by the process.

METHODOLOGY

Mapping is done on black-and-white aerial photographs, scale 1:20,000, with extensive field checking. Land color tone and pattern, relief, morphology, and vegetation are recognized on air photos, then environmental geologic units are derived and their areas outlined. The interpretation from air photos is checked by observing the same area on the ground. Because of the requirements of time and access, field checking was generally limited to areas of public access—highways, county roads, or parks. Only where a specific and significant problem existed were individual land owners contacted to obtain permission to look at private land. The agreement between boundaries identified on air photos and those observed on the ground during field checking was generally excellent. Personnel from various agencies such as the U. S. Soil Conservation Service were consulted to aid with the identification of nongeologic

features. Published data in the form of geologic maps and soils maps from the Soil Conservation Service were also consulted where available. Detailed soils maps are commonly very useful; most geologic maps, however, lump together varied lithologies and are too generalized.

After field checking, the environmental geologic units were transferred to U. S. Geological Survey 7 ½-minute quadrangle maps (1:24,000) and will eventually be compiled on a 1:125,000 base map for publication. The 7 ½-minute quadrangle maps are on open file at the Bureau of Economic Geology and are available for public inspection.

LOCATION OF INITIAL MAPPING

Initial mapping was in the Wilcox-Carrizo outcrop belt between the Colorado and Trinity Rivers (fig. 1). This area was selected for several reasons: (1) the Calvert Bluff Formation of the Wilcox Group is the major lignite-bearing unit (Kaiser, 1974); (2) the area includes two active lignite strip mines, a probable 3 billion tons of near-surface (less than 200 feet deep) lignite (W. R. Kaiser, personal communication, 1975), and at least two additional mines planned to be in operation by about 1980 (fig. 1); and (3) the Wilcox-Carrizo aquifer is recharged through the map area. Mapping is continuing along the Wilcox-Carrizo outcrop into northeast Texas and the Sabine uplift area of East Texas (fig. 1).

PURPOSE

Environmental geologic mapping provides information which can be used to avoid or alleviate some of the problems associated with lignite surface mining.

The mapping should (1) identify problem areas, (2) provide basic information for planning of reclamation, and (3) provide a regional framework for detailed studies of individual mine sites. Mapping should also identify areas which are relatively unreclaimable and particularly sensitive environmentally, such as aquifer recharge areas and floodplains. For planning of reclamation, the mapping provides an inventory of the materials, soils, and variations in relief and a general inventory of the

basic capabilities of the land. The mapping described here is regional in scope; detailed studies are necessary at individual sites.

Although the emphasis in this report is on the application of environmental geologic mapping to the problems of lignite strip mining, the use is not limited to those problems. Sensitive areas with

respect to lignite mining are also sensitive areas for other projects with potential environmental impact. The environmental geologic map can provide information for projects from building a town or highway to setting aside an area for recreational use. It also provides inventories of mineral resources such as sand and gravel, ironstone, and other aggregate materials.

GEOLOGIC AND HYDROLOGIC SETTING

GEOLOGY

The major lignite deposits of Texas are in three general geologic units: Wilcox Group, Yegua Formation, and Jackson Group (fig. 1). All are part of the Gulf Coast Tertiary province (fig. 4) composed of clastic sediments, various mixtures of sand, silt, and clay, which dip generally southeast at between $\frac{1}{4}$ and 2 degrees (about 20 to 180 feet per mile). All lignite presently mined is in the Wilcox—the mapping started there and included the Carrizo Sand, a major aquifer which occurs stratigraphically directly above the Wilcox Group.

In much of Texas, the Wilcox Group is undifferentiated sand and mud, deposited in fluvial systems in East and northeast Texas and in extensive barrier-bar and lagoon-bar systems in South Texas (Fisher and McGowen, 1967). The Carrizo Sand is composed primarily of coarse-grained meanderbelt and braided-stream deposits along with some lacustrine, lacustrine delta, and barrier-bar deposits (Davies, 1970; J. H. McGowen, personal communication, 1976). The Wilcox Group between the Colorado and Trinity Rivers has been subdivided into three formations (Barnes, 1970, 1974). From oldest to youngest, they are the Hooper Formation composed of mud and minor amounts of sand, the Simsboro Formation of sand, and the Calvert Bluff Formation of mud with various amounts of sand (fig. 4). The Calvert Bluff is the major lignite-bearing formation; however, lignite in the Hooper is also receiving exploration attention.

Detailed study of the Calvert Bluff Formation (W. R. Kaiser, written communication, 1976), indicates that it was deposited in a fluvial environment. Major channel deposits (thick sands) are isolated at the surface, surrounded by extensive

interchannel floodbasin deposits of sandy or silty clays and laminated sands and clays. The lignite seams are predominately in the interchannel deposits.

GENERAL HYDROLOGY

Though the Carrizo Sand and Wilcox Group are separate geologic units, sands within the two units are hydraulically connected either laterally along outcrop, vertically, or in the subsurface (Follett, 1970; Peckham, 1965). In general, the Wilcox-Carrizo is considered a single aquifer. This report will consider the Wilcox-Carrizo aquifer as composed of three components: the thick, laterally extensive Simsboro and Carrizo sands and the isolated (at the surface) channel sands in the Calvert Bluff. Rain falling on the ground surface runs off, evaporates, is transpired, or percolates through soil to the water table. Much potential recharge is rejected as the Wilcox-Carrizo aquifer, like most East Texas aquifers, is saturated with water to the land surface. Ground-water movement, determined from water-table elevations (Guyton and Associates, 1972), is mostly downdip to the southeast. In addition, there is a significant component of movement towards the major river valleys (Colorado, Brazos, Trinity) where some ground water discharges at seeps and springs. Streams within the outcrop area are effluent much of the year. The natural rate of ground-water movement ranges generally between 10 and 100 feet per year, with a few examples up to several hundred feet per year (Guyton and Associates, 1972). Recharge and rate of flow is controlled by the saturated nature of the aquifer; only as much water can enter the aquifer and move downdip as is discharged from the aquifer. Natural removal of ground water is by leakage through confining beds into stratigraphically higher aquifers and eventually to the surface. Flow rates would be considerably greater if the aquifer were pumped heavily.

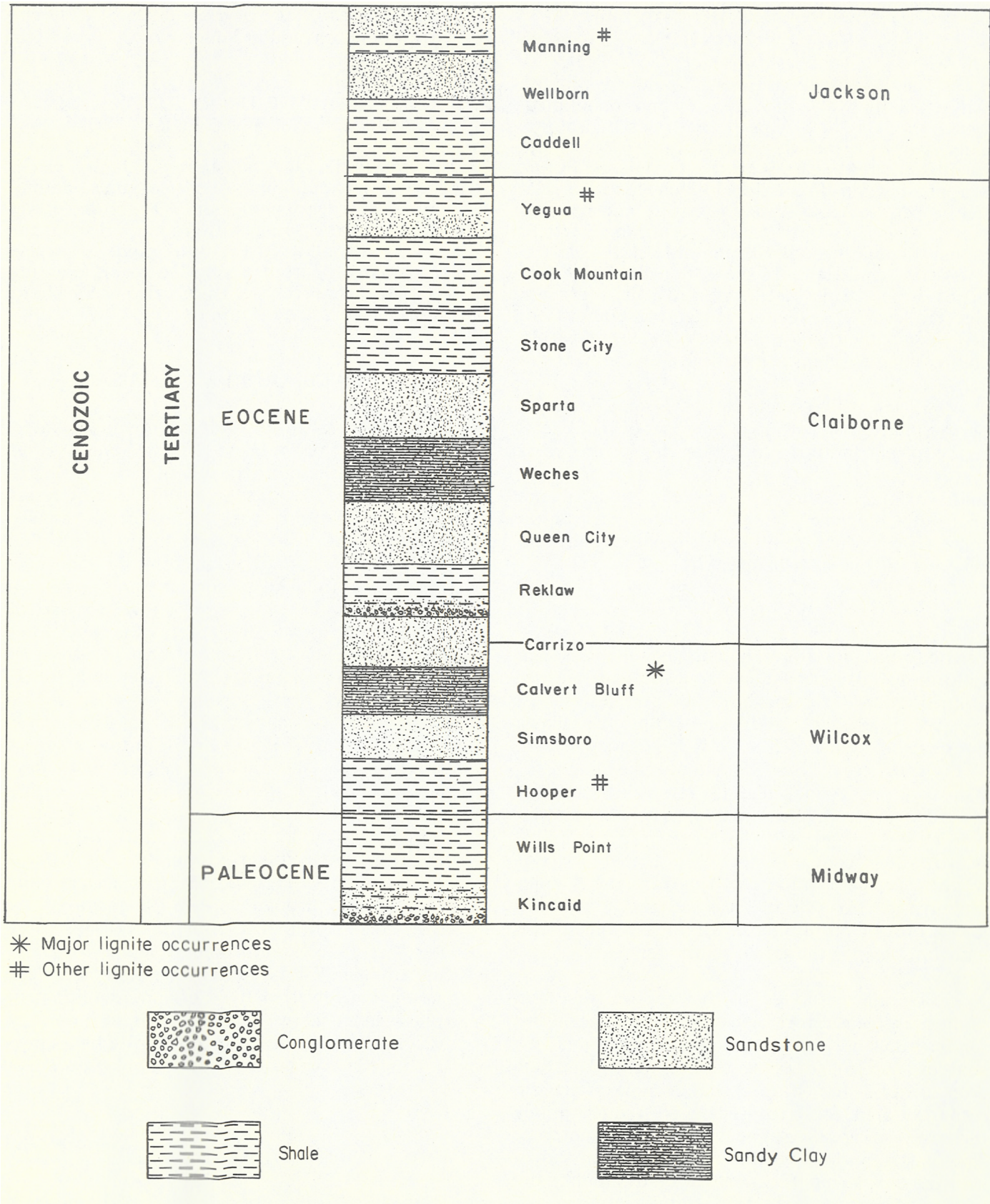


Figure 4. Stratigraphic column, East Texas; adapted from the Geological Highway Map of Texas (Renfro and others, 1973).

HYDROLOGY OF THE CALVERT BLUFF FORMATION

The depositional model developed for the Calvert Bluff by W. R. Kaiser (written communication, 1975) is highly pertinent to its hydrology. The highly permeable water-bearing parts of the formation are the sandy channel complexes. In this report, a sharp distinction is made between relatively permeable sands and relatively impermeable sandy clays. In simplified view, sand complexes are pipes running through impermeable clay. Figure 5 illustrates this view. It shows the distribution of major channels in the subsurface, derived from electric logs (W. R. Kaiser, written communication, 1975) and their surface expressions, derived from environmental geologic mapping.

All the Wilcox sediments have some degree of permeability; rain falling on any part of the Wilcox outcrop will infiltrate and enter the ground-water system to some extent. It is expected, however, that infiltration through the clean sands of the channel complexes greatly exceeds infiltration through the sandy clays and laminated sands and clays of the interchannel deposits.

Water contained in sand is more available for pumping than is water in sandy clays. Permeabilities for different substrates (expressed in gallons per day per square foot or gpd/ft²) are around 100,000 for gravels, 1,000 for clean sands, 1.0 for fine sand, and about .0001 for clays. Permeability values for some Wilcox sands in East Texas range from 17 to 338 and average 88 gpd/ft² (Guyton and Associates, 1972). Values are not given for the sandy clays as they are not commonly considered sources of water; however, permeability is probably around .01 gpd/ft², or 3 to 4 orders of magnitude lower than the Wilcox sands. A complete range from clean sands to muddy sands to sandy clays probably exists within the Wilcox with a similar range in the permeability values.

For the purposes of this report, the sand bodies are considered highly permeable, while the sandy clays are considered impermeable and not sources for ground-water development. The outcrop areas of the channel sand complexes are the recharge areas for the sands even though minor recharge occurs throughout the Wilcox outcrop. This is essentially the pipe-channel system shown on figure 5, a simplification that is justified for the regional approach used here. Detailed studies will be needed at individual mine sites to determine

precisely the ranges of permeabilities of different substrates encountered in mining.

HYDROLOGY OF THE CARRIZO SAND AND THE SIMSBORO FORMATION

The Carrizo and Simsboro sands are thick, laterally continuous, fine to coarse sands. Permeability values range up to about 500 gpd/ft². They are huge potential sources of ground water but are less likely than the Calvert Bluff sands to receive drainage directly from a mine. Streams draining mining areas may recharge the Carrizo or Simsboro sands as they cross their outcrops.

PRESENT GROUND-WATER USAGE

The Wilcox-Carrizo aquifer is the major water-bearing formation of East Texas. Several other formations, for example the Queen City and Sparta sands, are also water sources but are of lesser importance. Wells in the Wilcox-Carrizo supply water for most municipal and industrial uses in East Texas and for all rural, domestic, and livestock uses not fulfilled by surface water in areas in or immediately down dip from the Wilcox-Carrizo outcrop. Total use and availability of ground water is difficult to estimate for all of East Texas but an example—the four-county Anderson, Cherokee, Freestone, and Henderson area—is reported by Guyton and Associates (1972). In 1969 total pumpage from the Wilcox-Carrizo in that area was approximately 11 million gallons per day. Perennially available water with maximum development of well fields is estimated to be 52 million gallons per day within the four-county area alone, even with concurrent maximum use of Wilcox-Carrizo ground water in adjacent areas. Thus the Wilcox-Carrizo, though already a major water source, could potentially supply many times more water than it does at present. Figures for other parts of the Wilcox-Carrizo are not identical; however, the general pattern of underdevelopment of the aquifer is very similar. This inventory of land and water resources in the lignite belt shows that this extensive ground-water supply is a major future resource.

LAND USE

In the Wilcox-Carrizo outcrop area between the Colorado and Trinity Rivers, agriculture is the

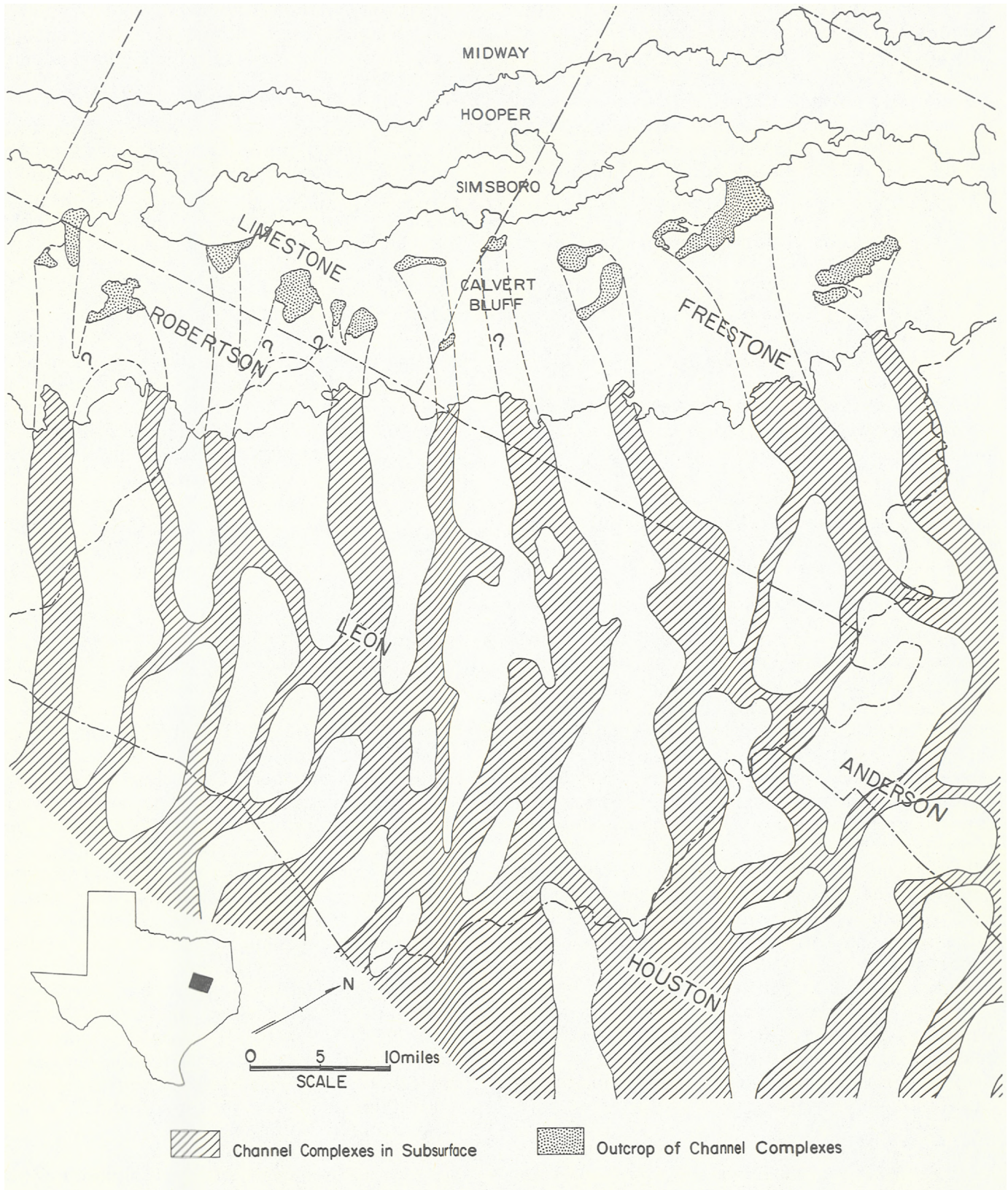


Figure 5. Map of subsurface channel complexes (W. R. Kaiser, written communication, 1975) and their surface outcrops (from environmental geologic mapping, Calvert Bluff Formation).

dominant land use. Most cleared land in the uplands is improved pasture; cattle raising is the largest cash-producing activity. Uncleared uplands, particularly with sandier soils, are also used for rangeland. The value of the land for recreational use such as hunting preserves is increasingly being recognized. Only minor amounts of land are cropland, cultivated mostly for forage with some local gardens.

Along major waterways, the more fertile

alluvial soils are heavily cultivated for cotton and grain sorghum. The bottomlands along moderate-sized streams are also cultivated, commonly for small grains.

A series of small towns (maximum population less than 10,000) provides trade centers for the agricultural areas nearby; the largest industrial centers are the two active lignite mines. Oil and gas production is mostly minor, and many of the fields are older ones now nearly exhausted.

RESULTS AND APPLICATIONS OF ENVIRONMENTAL GEOLOGIC MAPPING

INTRODUCTION

Twenty-three different environmental geologic units have been mapped in East Texas. More will likely be recognized as mapping progresses into new areas. Three groups of units—sands, sandy clays, and flood-prone areas—cover a majority of the area mapped and are the units most significant to surface mining. Table 1 lists characteristics of the environmental geologic units discussed in the text.

The discussion below illustrates how units are selected, what criteria are significant, and how the units are recognized on aerial photographs and topographic maps and on the ground. Most importantly, the discussion attempts to show in some detail how knowledge of the environmental geology can be applied in planning of lignite mining to avoid environmental degradation and to obtain successful reclamation. The discussions and examples are based on the area presently mapped. It is expected that other areas in East Texas will be similar. Areas in South Texas underlain by lignite were mapped in the Bureau of Economic Geology's Guadalupe - San Antonio - Nueces River basins regional study. The information from that project, though not aimed at lignite mining, also should be useful in the preparation of mining programs. Mapping approaches developed for the South Texas project were the basis for mapping in this study and have been refined for application to the East Texas area.

SANDS

Descriptions.—Two sand units are identified in this study—sand hills and low-rolling sands. The

substrate for each is similar, consisting of white or varicolored fluvial, fine to coarse quartz sands with rare clay lenses (fig. 6). The soil is highly leached loose sand of the Padina-Demona-Silstid association defined by the Soil Conservation Service. The vegetation cover consists of post-oak forest with hickory and blackjack oak and only a thin grass cover. Identification is, in part, made from air photos, based on the appearance of light-colored sands through the thin vegetative cover (figs. 7, 9).

Geomorphically, the sand hills unit stands up as rounded hills with moderate to steep slopes (3 to 10 percent, rarely up to about 16 percent) (figs. 7, 8). The low-rolling sands have shallower slopes (0 to 3 percent) with some large essentially flat areas (figs. 9, 10). Both units are recharge areas for the major aquifers of East Texas. The low drainage density observed on aerial photographs and topographic maps indicates that much of the rainfall infiltrates rather than runs off. Numerous small ponds within closed depressions in the sand areas are probably a reflection of a shallow water table. Mine drainage could enter an aquifer through these areas, and a pit which cuts through them could receive considerable ground-water discharge.

The difference in slope in the two units is significant both for present land use and in terms of mining. The low-rolling sands are more commonly cleared for cropland or pasture because of their lesser slopes. Both units require substantial fertilization before cultivation owing to the low nutrient content of the soils.

Figure 11 shows a conceivable situation which illustrates the difference in the two units in terms of mining. In figure 11A, a 10-foot-thick lignite bed is overlain by sands forming sand hills. A

TABLE 1. Characteristics of environmental geologic units.

ENVIRONMENTAL GEOLOGIC UNIT	SUBSTRATE	SOIL	SLOPE INTENSITY	NATIVE VEGETATION	PROCESS	PRESENT LAND USE
Sand hills	Friable, quartz sand	Sand, loamy sand, sandy loam	3 - 10%, rarely up to 20%	Post oak, blackjack oak	Infiltration, recharge	Aquifer, rangeland, improved pasture
Low-rolling sands	Friable, quartz sand	Sand, loamy sand, sandy loam	0 - 3%	Post oak, blackjack oak	Infiltration, recharge	Aquifer, improved pasture, rangeland
Low-relief sandy clay-forest soil	Sandy clay, laminated sand and clay	Fine sandy loam	0 - 3%	Post oak, elm	Runoff, gullyng, minor recharge	Improved pasture, rangeland
Moderate-relief sandy clay-forest soil	Sandy clay, laminated sand and clay	Fine sandy loam	3 - 8%	Post oak, elm	Runoff, gullyng, minor recharge	Improved pasture, rangeland
Low-relief sandy clay-prairie soil	Sandy clay, laminated sand and clay	Clay loam, hard fine sandy loam	0 - 3%	Prairie grass, mesquite, elm	Runoff, gullyng	Improved pasture, cropland
Moderate-relief sandy clay-prairie soil	Sandy clay, laminated sand and clay	Clay loam, hard fine sandy loam	3 - 6%	Prairie grass, mesquite, elm	Runoff, gullyng	Improved pasture, cropland
Floodplain	Clay, silt	Clay, clay loam	0 - 2%	Hardwood forest	Flooding, infiltration, runoff	cropland, improved pasture
Low terrace	Clay, silt	Clay, clay loam	0 - 2%	Hardwood forest	Infiltration, runoff, rare flooding	cropland, improved pasture
Mixed	Silt, sand	Silt loam, sandy loam	0 - 3%	Pin oak, post oak, pecan	Flooding, infiltration, runoff	Improved pasture, rangeland



Figure 6. Outcrop of trough-crossbedded fluvial sand, Simsboro Formation, Limestone County, composing the substrate for sand hills.

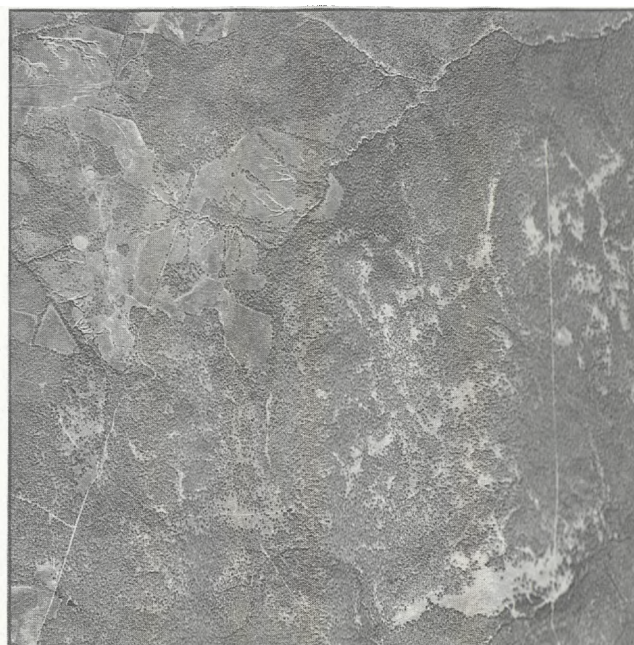
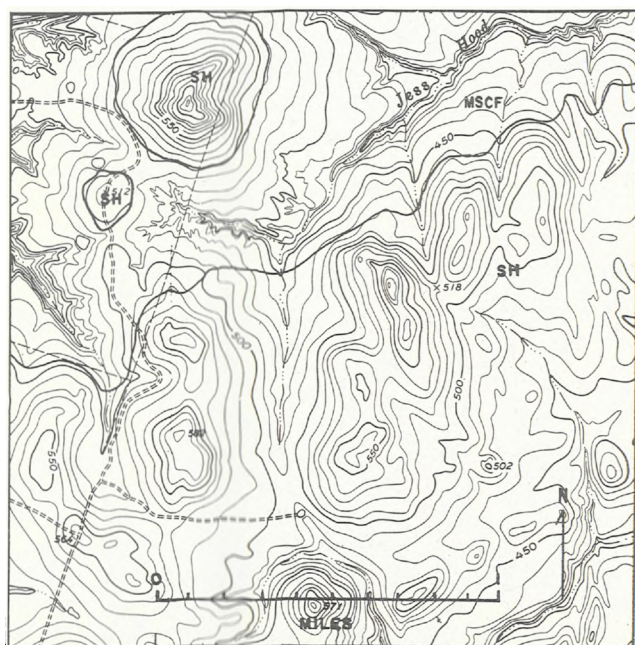


Figure 7. Aerial photograph and topographic map view of sand hills (SH) and moderate-relief sandy clay-forest soils (MSCF), Hanover Quadrangle, Texas.



Figure 8. Oblique aerial photograph of sand hill covered with post oaks surrounded by moderate-relief sandy clay-forest soils partially cleared for pasture, Freestone County, Texas.

mining company extracting the lignite would probably not mine very far beneath the sand hills; the sudden large increase in overburden thickness would require stripping to extract the lignite and would greatly increase the cost of extraction. A limit in terms of the thickness of overburden is reached when the cost of removing overburden exceeds the value of the lignite. One of the rare situations in which contour mining might occur in Texas is along a sand hills escarpment (for instance along the sand hills-sandy clay contacts shown on figure 7).

Figure 11B illustrates a similar geologic situation with low-rolling sands overlying the lignite. The overburden thickness increases gradually. Mining can extend much farther downdip than in the previous situation. The thickness of sand itself would probably not be the limiting factor in terms of overburden thickness. Thus, mining could extend through large sections of sand overburden.

Applications.—Strip mining through sands can create problems both for the environment and for mine operation.

Sands in this study area are saturated with ground water and will discharge into the pits. The discharge is a problem for mining, not an environmental problem created by mining. The amount of water discharged is a function of the thickness of saturated sand, the length of the pit, and the hydraulic gradient and permeability of the sand. Pumping the water from the pits adds to mining costs; also, much ground water can be lost for use.

The sands also present two important environmental problems: aquifer disruption and water pollution. Figure 12 shows a possible situation in which a mine cuts through an area of low-rolling sands. Sand body A, substrate for the low-rolling sands, will be isolated from the surface when mining and reclamation are completed. The perme-

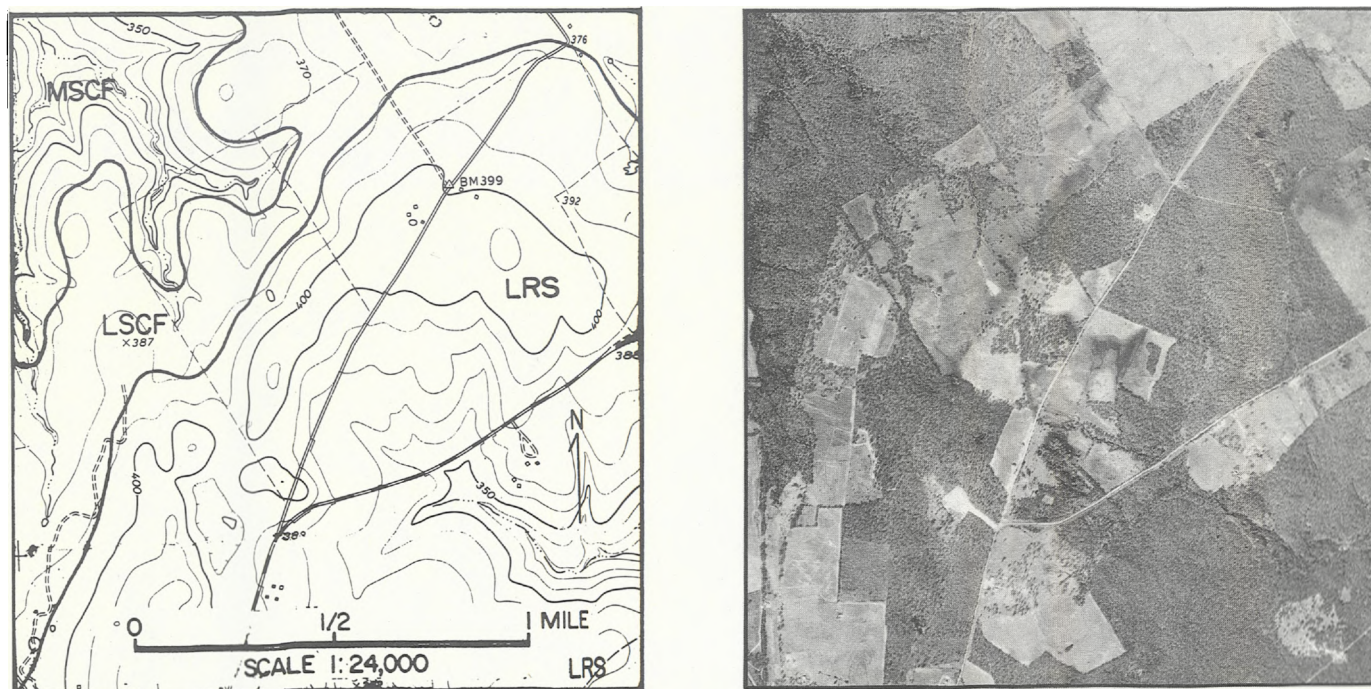


Figure 9. Aerial photograph and topographic map view of low-rolling sands (LRS) and low- and moderate-relief sandy clay-forest soils (LSCF and MSCF), Stewards Mill Quadrangle, Texas.



Figure 10. Field in low-rolling sands, Lee County, Texas.

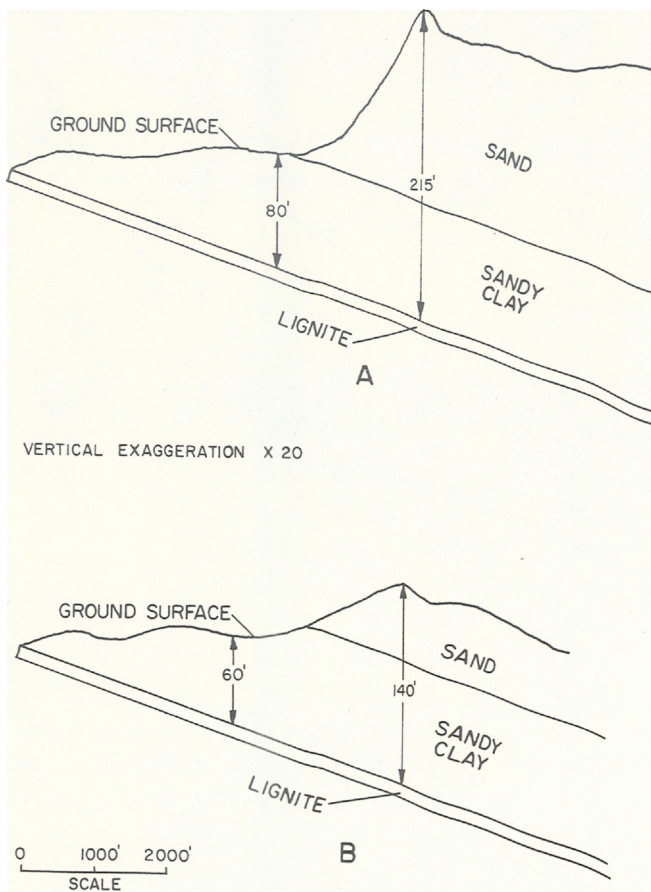


Figure 11. Schematic cross sections illustrating change in overburden thickness above lignite bed. (A) Sand hills; (B) Low-rolling sands.

ability of the compacted spoil material is likely to be variable, depending on the original nature of the overburden and the amount of compaction. A clayey, well-compacted overburden can effectively seal off the sand from any recharge. Heavy usage can exhaust the ground water in this portion of the aquifer.

If the overburden material is somewhat more permeable, the sand body will be recharged but only by water that has passed through the spoil material. This water will likely be of poorer quality than the original recharge and the quality of water within the aquifer will be diminished. The environmental geologic map identifies areas in which recharge can be altered physically or chemically. A map that identifies the sand recharge areas can be used as the basis for determining ways to deal with the problems. Mining could be restricted to areas away from such sand bodies and recharge areas.

Sand bodies, however, are common throughout the Calvert Bluff Formation, and this approach would remove some lignite from potential use.

Rerouting mine drainage away from the sands is a possible solution. In the situation shown by figure 12, rerouting would require sealing the sand body along the walls of the pit with impermeable material, thus cutting off the sand from recharge.

Monitoring the water chemistry of the sand body down hydraulic gradient from the lignite pit identifies ground-water contamination but does not prevent mine-water discharge. The geometry and permeability of the sand body can be determined by using the environmental geologic map and core information. With this knowledge, properly placed wells can monitor the flow of mine effluent and its effect on the ground-water quality (wells A and B, fig. 12). Several points need to be emphasized concerning figure 12. Sand A will be exposed in the highwall and will not receive mine drainage (or any recharge) until mining is completed and the pit filled in. Ground-water contamination will occur only after mining has ceased. Monitoring must continue after mining. During mining, mine drainage could percolate through the moderately permeable sandy clay underlying the lignite to reach sand B. Monitoring wells must be carefully located to provide the information necessary to evaluate the effects of mining on ground water. Well C in figure 12 does not intersect either sand body, and analysis of water from the well would indicate nothing about the flow of mine drainage.

Figure 4 combines regional environmental geologic mapping and regional subsurface mapping from electric logs. Only major sand bodies extending 1 to 4 square miles in outcrop area are shown. In terms of amounts of water and permeability, these are probably the most important parts of the Calvert Bluff aquifer. Sand geometry is clearly illustrated; sites for monitor wells can easily be selected from the sand geometry and, of course, location of lignite mines.

Monitoring surface drainage from lignite mining areas is not sufficient to determine problems of mine drainage. Rain water falling on an unreclaimed mine area can follow several flow paths (fig. 13). It is assumed that enough previous rain has fallen so that the spoil in the old mine pit is saturated and the water table is near land surface. Path A is for rain water that falls on the spoil and runs off without percolating through the

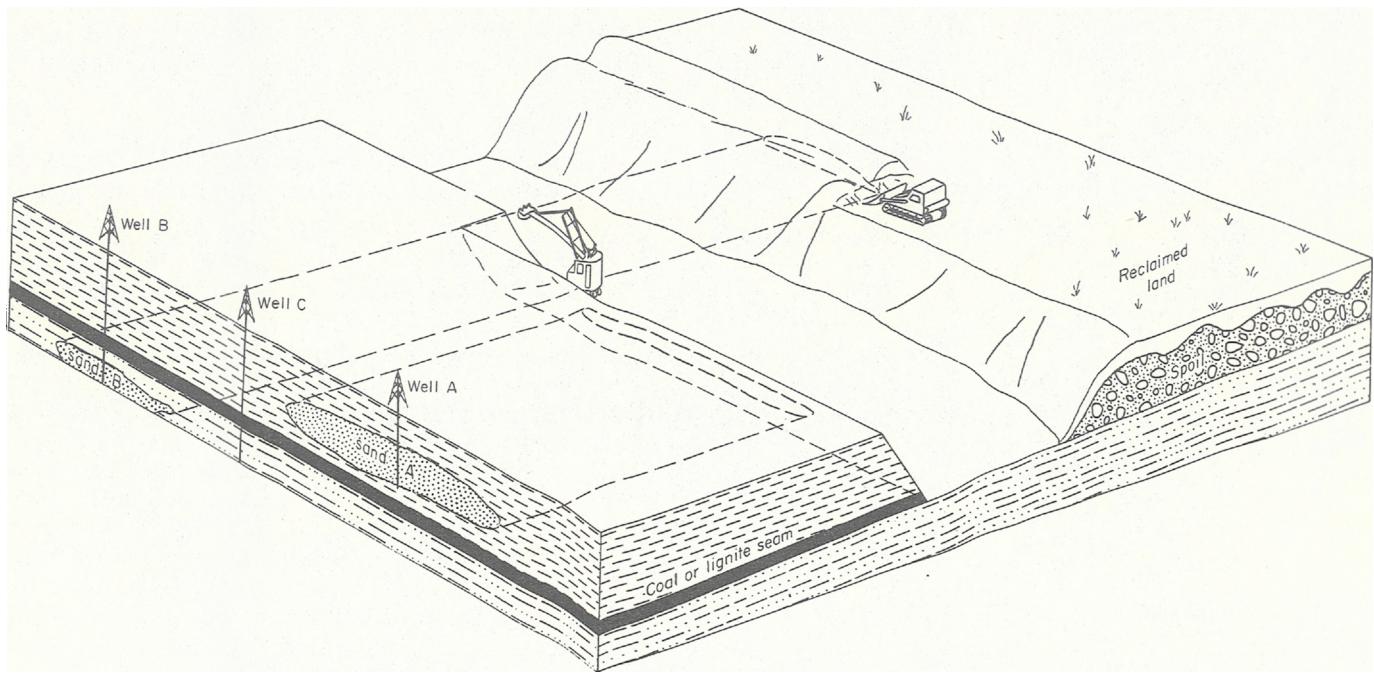


Figure 12. Schematic diagram of hypothetical lignite mine showing water-quality monitoring in sand body intersected by mining (sand A) and sand body beneath lignite (sand B). Well C does not intersect either sand body and would not be useful in monitoring mine drainage.

spoil. The water will be little affected by reaction with any compounds within the spoil. Water in Paths B and C infiltrates a short distance but comes out at seeps and springs along the edge of the spoil entering the surface drainage or ponds within the spoil. The water will have been in contact with spoil and pyrite within the spoil only briefly. Along Path D, on the other hand, water travels a great distance through the spoil, never returning to the surface before entering the sand aquifer. Thus, there is a greater opportunity for reaction with pyrite to produce poor quality waters. In addition, because it never returns to the surface, the water will not be oxidized. Unoxidized water commonly can dissolve much greater concentrations of trace metals, such as iron and manganese, than oxidized water (Hem, 1970), and the adsorption of other trace elements (for instance copper, lead, and zinc) by precipitating ferric hydroxide (reaction 3) will not occur in unoxidized water (Hem and Skougstad, 1960). The sample from the Fairfield mine which contained 65 mg/l dissolved iron (Lentz, 1975) was from a seep which must have followed a path similar to B or C (fig. 13). Gradations should be expected between these paths. However, it should be clear that surface water draining from a lignite mine will have

undergone a different history and have a different composition from water which drains out through the subsurface.

Mine drainage can be monitored by wells down hydraulic gradient from the mine. Well #1 on figure 13 accomplishes this objective. Well #2 does not penetrate the sand and would not monitor mine drainage.

SANDY CLAYS

Descriptions.—A large part of the Wilcox Group is underlain by sandy clays or finely laminated sands and clays (fig. 14). Most of this material is probably overbank material deposited between major channel systems. Lignite seams are predominately within this kind of substrate.

Two general kinds of sandy clays have been distinguished on the basis of their soil associations—prairie soils and forest soils. In mapping, each was further subdivided on the basis of slope intensity. The prairie soils are clay loams or hard, fine sandy loams with thick clay "B" horizons. They are part of the Crockett-Wilson or

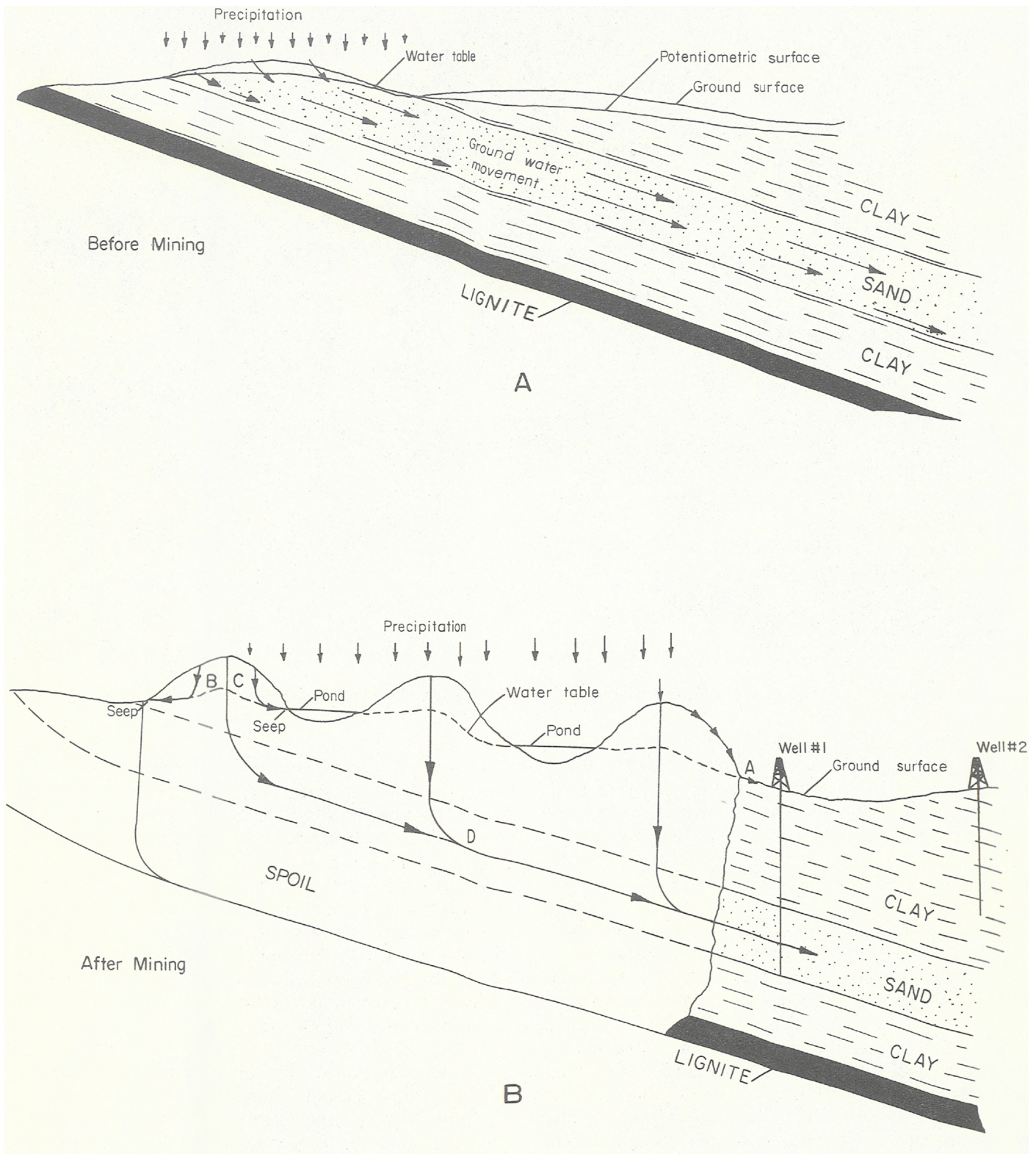


Figure 13. Precipitation and surface- and ground-water flow paths before and after mining which intersects sand aquifer; the after-mining view is before reclamation. Flow paths (A, B, C, D) in after-mining view are discussed in text.



Figure 14. Sandy clay and laminated sand and clay overlying lignite in clay pit, Freestone County, Texas.

Wilson-Burleson soils associations and are more related to the Blackland Prairie farther to the west than to the Post-oak Savannah which dominates much of the lignite area. The native vegetation, except along stream courses, consists of prairie grasses and mesquite (fig. 15).

The prairie soils have severe shrink-swell problems characteristic of many clay soils. However, gilgai structures as described by Gustavson (1975) are restricted to more pure clay substrates.

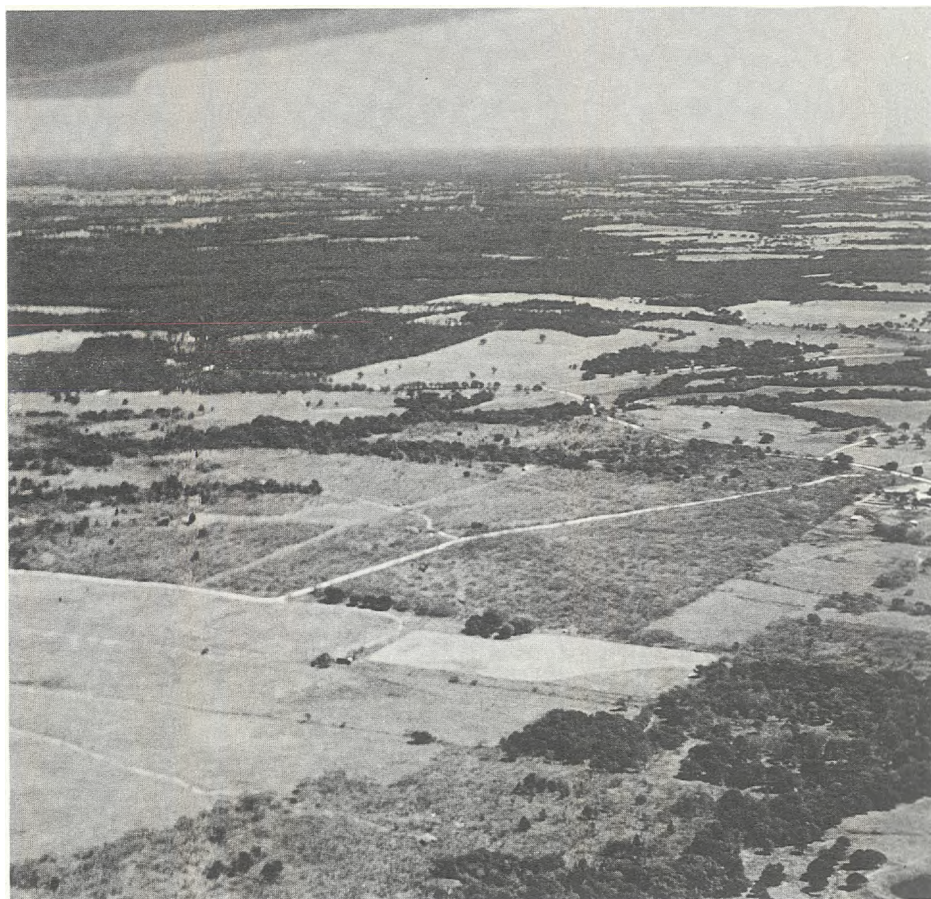
The forest soils have sandy "A" horizons up to several feet thick over clay loams (fig. 16). They are generally members of the Axtell-Tabor association and support thick post-oak forests. The presence of clay "B" horizons produces moderate shrink-swell problems.

Near the Colorado River, total areas of prairie and forest soils are approximately equal. Towards the northeast, forest soils become dominant

because of a combination of factors including a more sandy substrate and an increase in rainfall, possibly leading to greater soil leaching and differentiation. Both sandy clay units are extensively used for improved pasture. Only a small percentage is cropland, and much which was previously cropland has been allowed to go back to pasture or even forest. Both units have severe erosional problems which have been aggravated by past agricultural practices. Erosion of steep-walled gullies has removed top soil and made large areas unsuitable for any use (fig. 17).

Recognition of the units is based on (1) the dark- to light-gray or mottled-gray tone shown on air photos, (2) the gently rolling topography, (3) the common presence of gullies, and (4) the fact that much of the land is cleared (figs. 7, 9). The different soil associations were distinguished largely on the basis of native vegetation present and by U. S. Department of Agriculture Soil Conservation Service soil maps where available.

Figure 15. Area of low-relief sandy clay-prairie soils—mesquite trees in middle distance; cleared for pasture in left foreground; sand hills and moderate-relief sandy clay with forest soils in background.



Contained within the sandy clays are scattered sand lenses which are too thin to be distinguished on the air photographs. A lower limit of thickness for recognition from 1:20,000-scale photographs with the prevailing 1° dip is approximately 20 feet. Such sand bodies have necessarily been included with the sandy clays. Probably these sands were deposited by minor tributaries to and crevasses from major channels.

Applications.—The major lignite seams are intercalated within the sandy clay and laminated sand and clay substrate of these units. A large part of the lignite mining will occur in areas of sandy clays. Thus, the environmental geologic map provides an inventory of material, especially soils and soil quality in terms of potential and present land use, and examines the capacity of the substrates for reclamation. In addition, this inventory indicates the relative need for preservation of the soils.

Though the soils of the East Texas uplands generally are not highly fertile, their characteristics

and distributions must be known to evaluate the need for segregation during mining. The Soil Conservation Service rates various soils on the basis of their agricultural productivity and also typifies soils as potential pasture, cropland, or rangeland. The prairie soils of the Crockett-Wilson association are identified as cropland. Production potential per acre under high-level management is approximately 400 pounds of cotton or 3,000 to 3,200 pounds of grain sorghum; as pastureland, production during normal years is around 5,000 to 5,500 pounds of air-dry herbage.

The forest soils of the Axtell-Tabor association are typified as pasture land. Their production potential is considerably lower than the prairie soils: 200 to 250 pounds of cotton, 2,000 to 2,200 pounds grain sorghum, or 3,000 pounds air-dry herbage. Thus the prairie soils are suitable for higher intensity agriculture and, in general, are more productive than the forest soils. In preference to forest soils, prairie soils would need to be segregated and saved for reclamation during mining.



Figure 16. Substrate and sandy loam soil of low-relief sandy clay-forest soils. Top of shovel marks base of "A" horizon; point of shovel is about at base of "B" horizon. Borrow pit, Freestone County.

None of the soils in the areas presently mapped is used for commercial timber production. However in East Texas, timber is a major industry, and the productivity of soils for pine and hardwoods will need to be considered.

The presence and restriction of gullies to areas of sandy clays indicates that, among the various substrates in the lignite areas, the sandy clays are most susceptible to erosion. Disruption of the land surface caused by strip mining will increase the potential for erosion. Overburden composed of sandy clays will need to be regraded and revegetated soon after mining to avoid excessive erosion.

Some sand lenses contained within the sandy clays are too small to map at a scale of 1:20,000. As they are potential conduits for mine drainage, they will need to be identified during detailed

studies at the mine site. Though the sandy clay is assumed to be impermeable for the purposes of this simplified discussion, it does have some permeability. Mine discharge could move through this material to more permeable horizons which might not otherwise receive mine drainage. This possibility needs to be evaluated.

FLOOD-PRONE AREAS

Descriptions.—Three different units are potential flood-prone areas. They are: (1) floodplains, (2) mixed alluvium and colluvium, and (3) low terraces (fig. 18).

The overriding criterion for classification of floodplains is the process, flooding. Substrates are commonly silts and clays near the surface grading downward into coarser material. Soils reflect the substrate upon which they developed and are commonly very fertile and highly cultivated. Recognition on aerial photographs is not difficult. Evidence of erosion and deposition, such as ridge-and-swale topography (fig. 18) and point bar deposits (fig. 19), is common and distinctive. The floodplains are nearly flat, commonly have a sharp topographic break at their boundary with adjacent upland, and show a distinct tonal difference between the dark-toned, water-saturated clayey soils of the floodplain and the lighter toned, drier soils of the uplands. Floodplains up to several miles wide, commonly called bottomlands in East Texas, border some of the larger rivers. Smaller streams have correspondingly narrower floodplains. Flooding in these areas is frequent; for many medium-sized rivers, a 4-inch rain in 24 hours is sufficient to produce a flood which will cover most of the bottomland. Such a rainfall and flood can occur once every few years or possibly several times in 1 year.

Some major rivers, notably the Brazos and Colorado, have numerous flood-control structures designed to prevent or reduce the probability of flooding. The presence of these structures has encouraged development and even home construction on floodplains. Their effectiveness in preventing all flooding is beyond the scope of this report. Baker (1975) points out that the New Braunfels flood of 1972 was caused by heavy rain which fell on only a small part of the drainage basin below Canyon Dam. Natural floodplains



Figure 17. Gully system developed in laminated sand and clay of moderate-relief sandy clay-forest soils, Robertson County, Texas.

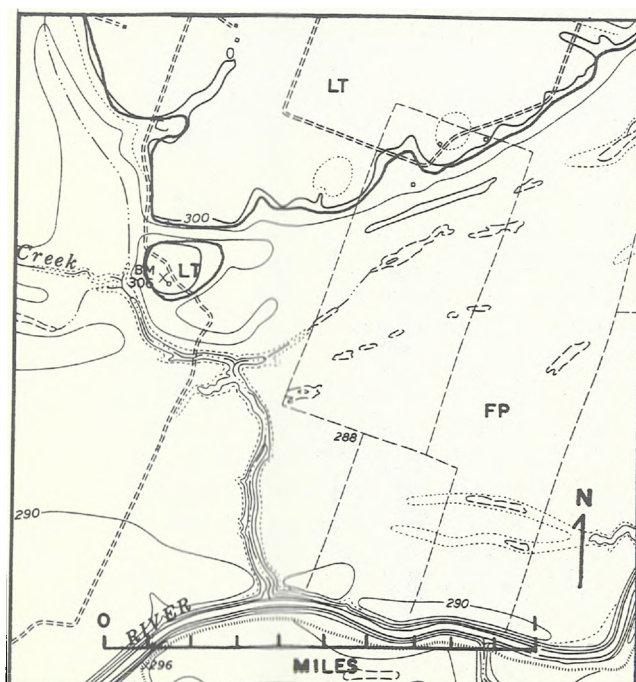


Figure 18. Aerial photograph and topographic map view of floodplain (FP) and low terrace (LT), Hanover Quadrangle, Texas.

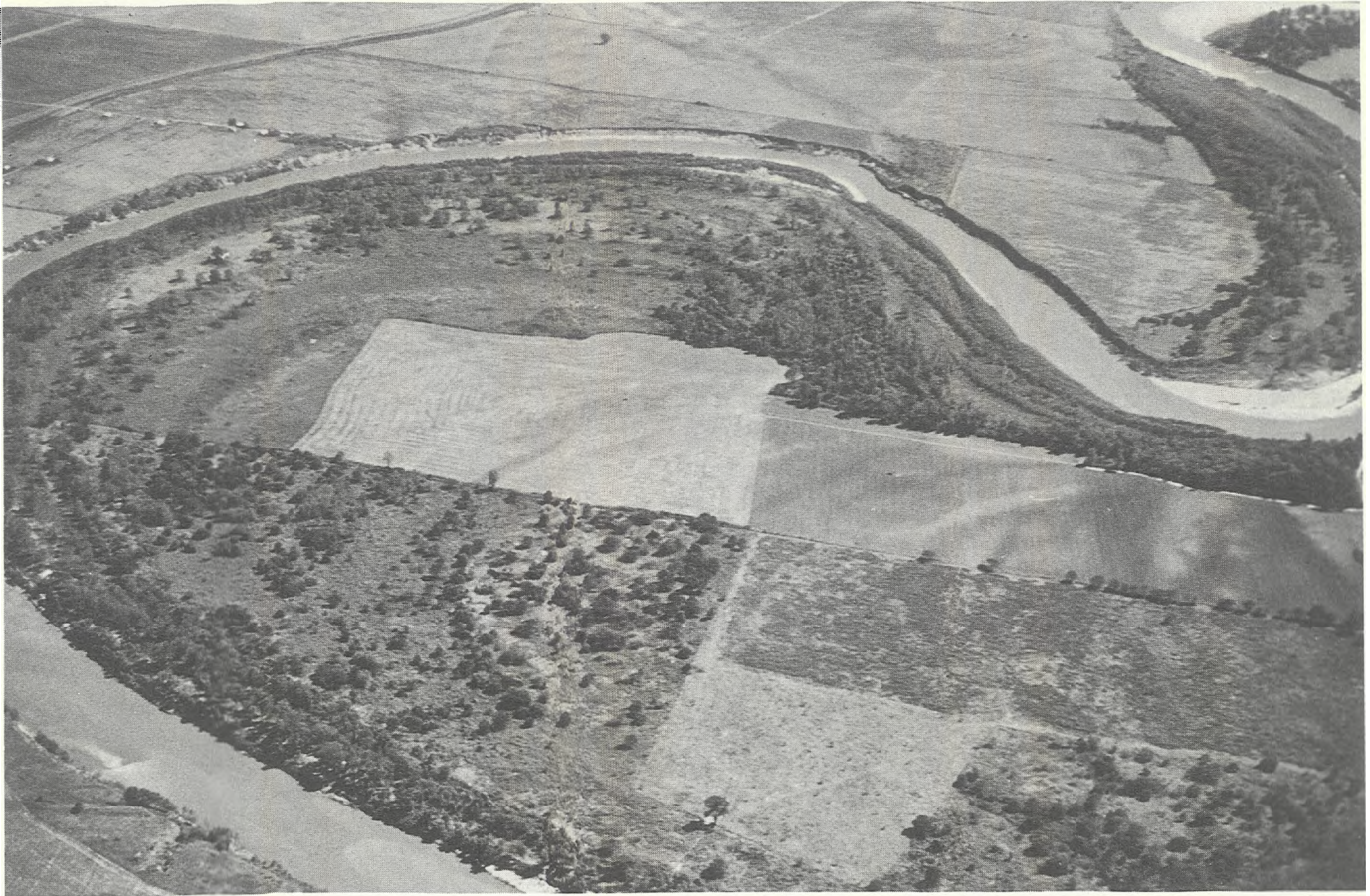


Figure 19. Oblique aerial photograph of point bar deposits along Brazos River, Milam and Robertson Counties, Texas.

were mapped in this study without consideration of flood-control structures.

The mixed unit consists of interfingering alluvium deposited by streams and colluvium washed down from the slopes above the streams. This unit commonly occurs along smaller streams where the contribution of sediments from colluvial and alluvial processes is relatively equal. Mixed units generally have concave-upward surfaces, and the break between pure colluvial and pure alluvial material cannot be precisely located. Some areas are small floodplains which are not distinguishable at the scale of this mapping. Flooding on these mixed areas is at least as frequent as on the larger floodplains; however, the volume of water involved is considerably smaller.

The third flood-prone area consists of numerous low terraces adjacent to the floodplains of medium to larger sized rivers (fig. 18); these low

terraces are designated low-probability flood-prone areas. Terraces as much as 100 feet above adjacent floodplains are recognizable; clearly these would not flood during even the largest magnitude flood. Low terraces are those that are no more than 10 feet above the floodplain. These low terraces do not show the geomorphic evidence of flooding that the true floodplains do and there is commonly a distinct, albeit low, topographic break between the two. Though the 10-foot difference is a relatively arbitrary figure, historical data (United States Geological Survey Water Stage Records and personal recollections of local residents) indicate that the low terraces have been flooded during large-magnitude flood events.

No quantitative recurrence interval is implied for these flood areas. Recognition has simply been made of the fact that these areas have been flooded in the past and will be flooded again. In relative terms, the floodplain and mixed units experience

flooding far more often than the low terraces. From comparison with U. S. Geological Survey maps of flood-prone areas derived from hydrologic data, the combination of floodplains and low terraces correlates roughly with the 100-year floodplain recognized by the U. S. Geological Survey.

Applications.—Flooding has obvious implications for mining. Flood waters could destroy equipment, wash overburden back into the pits, flood the pits, and otherwise retard mining operations. Large quantities of suspended solids would be added to the flood waters by mine areas, further increasing the problem of siltation.

Use of most floodplains in East Texas has been restricted to agricultural activities which can withstand occasional flooding. Significant lignite deposits exist under some of the floodplains. The value of the lignite dictates that people will try to devise methods to recover it; however, few mining companies would gamble on mining on an unprotected floodplain.

Other factors are significant in mining on floodplains. Ground-water discharge into the mine could be a problem. Mining of lignite would first have to remove up to 75 feet of alluvium deposited by the river (Cronin and Wilson, 1967). Alluvium commonly grades downward from fairly fine material at the surface to coarse material, even gravel, at the contact with the underlying Wilcox deposits. The lower portion of the alluvium is saturated and would discharge continuously into the lignite pit, making continuous pumping of the mine necessary. Permeability values determined for Brazos River alluvium (Cronin and Wilson, 1967) range from .001 for silt and clay to 18,000 gpd/ft² for gravel. Transmissibility values range from 50,000 to over 300,000 gpd/ft². Permeability and transmissibility values are not available for alluvium along other major rivers but are probably similar.

Floodplain alluvium contains a large amount of ground water which is not extensively pumped except along the Brazos River where it is used for

irrigation. In 1964 over 48,000 acre feet of water, or 16 billion gallons, was used for irrigation in the stretch between Whitney Dam and Richmond (Cronin and Wilson, 1967). This figure represents 98 percent of the total amount of water pumped from Brazos River alluvium in that stretch. Annual recharge varies according to annual rainfall but averages about three times the present withdrawal; use could increase without depleting the aquifer. The water is of variable quality but is suitable for agricultural use. Most of it is suitable for domestic use, though domestic use will likely continue to be minor. Mining could reduce the quality of the alluvial water. How serious the reduction in quality could be would depend on a number of factors. Mine drainage would undoubtedly move very rapidly through the highly permeable alluvium; however, ground water in such large volumes may dilute the drainage to the point that it does not affect agricultural use. Predictions of the deterioration of water quality can be made with adequate geochemical and hydrologic data.

Soils on floodplains.—Floodplains and terraces contain some of the most productive soils in East Texas. The Brazos floodplain is heavily farmed; primary crops are cotton and grain sorghum. Other floodplains, such as along the Trinity River, have fertile soils, but the lowest lying areas are not cultivated extensively at present because of frequent, prolonged flooding. The Brazos floodplain and its soils will be used as an example but other rivers have similar potential. The Brazos soils belong to the Miller-Norwood association of the Bottomland land resources area. Annual yields are approximately 450 pounds of cotton or 6,000 pounds grain sorghum per acre. The Miller clay is considered one of the finest cotton soils in Texas. Potential yield of air-dry herbage is approximately 9,000 pounds per acre in normal years.

These soils are important resources. If mining is undertaken in floodplain areas, the agricultural productivity of the floodplains and terraces requires that the soils be segregated and preserved during mining and restored afterwards.

SUPPORTIVE STUDIES NECESSARY AT INDIVIDUAL MINE SITES

The environmental geologic map points out some of the problem areas for strip mining. The regional approach to mapping described here

requires that certain factors will need to be further studied in detail at individual mine sites. Some features are too small to be recognized on air

photos; others, such as the chemistry of the overburden and lignite, are not observable on air photos. Additional necessary information includes detailed inventories of the types of soils present, their areal extent and distribution (which can be obtained from larger scale aerial photos), and the quality of the soils in the area. Much specific information can only be obtained from electric logs and cores. Drilling is necessary for exploration and development of a lignite seam. An additional cost will be incurred for studying and analyzing drilling results in terms of environmental problems; however, a separate drilling program should not be necessary, and much of the information necessary for mining will also be applicable to environmental protection.

Information that can be obtained from drilling programs includes detailed knowledge of the geometry of the aquifer system around a mining area and the permeability, transmissibility, and other hydraulic parameters of different parts of the aquifer. Information concerning the amount, distribution, and form of (1) pyrite or other acid-generating material, (2) carbonate minerals or other acid-neutralizing material, and (3) toxic elements or compounds in the lignite and overburden can be obtained from chemical and microscopic analysis of cores. Some of this chemical data will have already been compiled to determine the value of lignite as fuel. The application of knowledge about the geometry of an aquifer has already been illustrated. With drilling information, that knowledge can be applied at the detailed scale of the mining operation. A well field can be located in and adjacent to the mine; the wells would accurately monitor the development and movement of any mine drainage.

The immediate and long-term potential for production of acid drainage can be evaluated by knowing the amount, distribution, and form of

pyrite and carbonate minerals. The acid-production potential of coal is a function of the form and amount of pyrite. Caruccio (1970) emphasized that fine-grained, "amorphous" pyrite is more reactive than coarse pyrite. The distribution of pyrite will determine whether or not acid produced by oxidation will come into contact with neutralizing material. Carbonate closely mixed with pyrite may inhibit oxidation of the pyrite (Caruccio, 1968). For example, if carbonate minerals are sufficiently abundant and well distributed to neutralize the potential acid production from oxidation of pyrite, a major water quality problem may never develop. On the other hand, there may not be enough carbonate to neutralize all potential acid generated. Initially acid might be neutralized, but eventually the carbonate minerals would be depleted and acid would not be neutralized. Even if carbonate sufficient for neutralization is available within the spoil, if the carbonate and pyrite do not occur together, acid produced might never come in contact with carbonate and might not be neutralized. In these last two situations, lime or some other neutralizing agent may need to be added to the spoil material.

Chemical information on lignite and overburden is also pertinent to planning of reclamation and revegetation. The capability of mixed overburden to produce an adequate soil is dependent upon its texture and chemistry (including nutrient content) and time. Mixed overburden will have significantly more clay than many of the sandy soils of East Texas. Large amounts of pyrite in the spoil may produce a new soil which is too acid and which has excessive amounts of some elements. Decisions to preserve original soils must be based on careful comparison of the quality of the soil with the mixed overburden that could potentially replace it. The choice of reclamation methods will depend on the physical and chemical properties of the spoil.

SUMMARY AND CONCLUSIONS

Interest in Texas lignite has increased dramatically in the last few years. Texas is becoming a major coal-producing state, and reasonable projections show a continued increase in lignite production.

Large areas of the State, particularly in East Texas, will be strip-mined to obtain the lignite.

Coal strip mining has caused environmental degradation in several parts of the United States. Similar problems could occur in Texas unless adequate planning based on thorough inventories of natural conditions is undertaken prior to mining.

Environmental geologic mapping provides much of the information necessary to plan mining

and reclamation. The environmental geologic map does three things: (1) it identifies problem areas, (2) it provides basic information for planning of reclamation, and (3) it provides a regional framework for detailed studies at individual mine sites. Some examples of critical areas identified by the mapping for this study are aquifer recharge areas (sand hills and low-rolling sands) where the potential for ground-water pollution must be given strong consideration, sandy clays which are the probable substrate in which most mining will occur, and floodplains which would be hazardous areas for mining and which have highly fertile soils requiring preservation.

This report does not attempt to identify every environmental problem or problem area. It does point out the utility of environmental geologic maps in providing the basic framework necessary to anticipate and deal with environmental problems.

Lignite mining in Texas is likely to be a major source of energy, a major land use, and a major job and money producer. Lignite, however, is a non-renewable resource; once burned it is gone. Land and water are renewable resources and, if properly protected during mining, can provide food, fiber, and recreation indefinitely.

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